A UNIVERSALLY TRANSPARENT FIBER OPTIC NETWORK FOR BUILDINGS, FACTORIES AND CAMPUSES

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ABSTRACT

The design of a fiber optic network that can support most, if not all, of the telecommunication needs of an intelligent building is described. The design can also meet the needs of factories, campuses and hospitals. Advantages of the design are discussed and some application examples are given.

The impact on the construction industry is considered and the need to facilitate the emergence of Fourth Utility General Contractors is pointed out.*

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* *The fourth utility refers to telecommunication systems and services. The first three utilities are water (i.e. plumbing), electricity (i.e. wiring) and air (i.e. HVAC: Heating, Ventilating & Air Conditioning).*

This paper was presented at the 6th Canadian Construction Congress 1990 which was held in Toronto, Ontario, in December, 1990. The Canadian Construction Research Board selected three papers from the more than 40 papers that were submitted to the Congress and awarded $ 5,000 each to the authors of the three papers. This paper was among the three that were selected.

1.0 INTRODUCTION

In office buildings, the largest expenditures are related to people in terms of wages and benefits, business operations and management. The cost can easily exceed that of the capital investment in a building. The same may be said of factories and campuses.

To maximize the return on these expenditures, computer hardware and software such as PCs (Personal Computers), word processors and external data bases, as well as telecommunication services such as facsimile and teleconferencing are used. This is reflected in the increasing trend towards OA (Office Automation).

Interest in a healthy, pleasant, safe and secure work place also reflects the management concern for a higher return on the cost of pay and benefits. For a motivated staff, it is self-evident that productivity will be high in a work place that is pleasing and if support is also provided by suitable equipment.

Building management systems such as HVAC (Heating, Ventilating & Air Conditioning) and access control can provide the desirable work climate while electronic hardware and software can provide the necessary OA support. An intelligent building might be defined in terms of various features that are offered by the building management and OA systems.

Common to the two systems is what can be called the fourth utility, the telecommunication systems and services. The first three utilities are, of course, water (i.e. plumbing) electricity (i.e. wiring) and air (i.e. HVAC). Regrettably, the importance of the fourth utility has often been underestimated by the designers of so called intelligent buildings.

Normally, the fourth utility is provided by a multiplicity of copper wire networks. They support a wide range of systems such as telephone, LANs (Local Area Networks) and HVAC. Problems arising from electrical ground loops, signal crosstalk, EMI (Electromagnetic Interference) and RFI (Radio Frequency Interference) frequently lead to expensive post-installation debugging operations.

Also, when a new system such as lighting control is to be added, a separate copper wire network must be installed. This often incurs extra costs due to congested conduits and raceways.

The advantages of fiber optic transmission systems for long distance telephone trunk lines are well established today and the technology is now being applied to trunk lines from the CO (Central Office) to high-rise office buildings. The features of immunity to EMI, RFI, absence of crosstalk and ground loop problems, and the large transmission capacity are appreciated universally today.

Despite the success in trunk lines, fiber optics technology has not been applied widely to fourth utility networks for buildings, factories and campuses. The major reasons are the perceived high cost of the technology and the lack of systematic design efforts to satisfy the diverse needs encountered in such applications. In other words, technical experts have pushed the technology instead of producing a design by understanding the needs first.

The following sections describe a systematic design of a universally transparent fiber optic network for intelligent buildings, factories and campuses, and the demand such a design will impose on the construction process of buildings is also discussed.

2.0 FIBER OPTIC NETWORK DESIGN

A universally transparent fiber optic network for intelligent buildings must support a wide range of digital and analogue signals. Systems such as CCTV (Closed Circuit Television) need 5 MHz analogue bandwidths while some LANs have bit rates in excess of 10 Mb/s.

In addition, the network must readily adjust to office moves and renovations. The former is of particular importance because the "office churn" in North America occurs frequently. Also, the addition of new systems should be accommodated without major expenditures. In other words, flexibility is demanded of the network in the rapidly changing milieu of electronics.

Table 1 lists the desirable features of a universally transparent network. Clearly, digital signal bit rates from DC to over 10 Mb/s must be supported. The former arises from contact closures in HVAC and other building management systems while the latter arises from LANs and high speed computer work stations. Analogue Video/Audio signals such as those from CCTV for security systems must also be supported. Of course, the list in Table 1 is not exhaustive.

Figure 1 shows a network design that provides the features listed in Table 1. The design is denoted as Net-Five with the notion that it supports the fourth utility of an intelligent building as well as the needs of fifth generation computers.

3.0 NET-FIVE FIBER OPTIC FOURTH UTILITY NETWORK

The Net-Five network has a star configuration in contrast to many high speed fiber optic networks which are usually configured as a ring. The two are compared in Table 2. Obviously, the star

TABLE 1 FEATURES OF A FOURTH UTILITY NETWORK

Desirable features of a network for an intelligent building are listed. The network considered here corresponds to the Physical Layer (i.e. Level 1) of the ISO (International Standards Organization) 7-layer OSI (Open Systems Interconnection) Reference Model. The list is by no means complete.

FOURTH UTILITY NETWORK FEATURES
• **OSI STANDARDS COMPATIBLE** ISDN RS-232C RS-422 RS-423 RS-485 X.21 X.21 bis • **BUILDING MANAGEMENT SYSTEM CONNECTIONS** HVAC LIGHTING CONTROL ACCESS CONTROL PAGER PERSON LOCATER FIRE & SECURITY ANALOGUE VIDEO/AUDIO • **TELECOMMUNICATION SYSTEMS CONNECTIONS** PBX TELEPHONE (ANALOGUE & DIGITAL) CENTREX TELEPHONE (ANALOGUE & P-PHONE) T1 = 1.544 Mb/s LAN & COMPUTER CONNECTIONS ETHERNET ARCNET TOKEN PASSING IBM 3270 SUN WORKSTATION FDDI

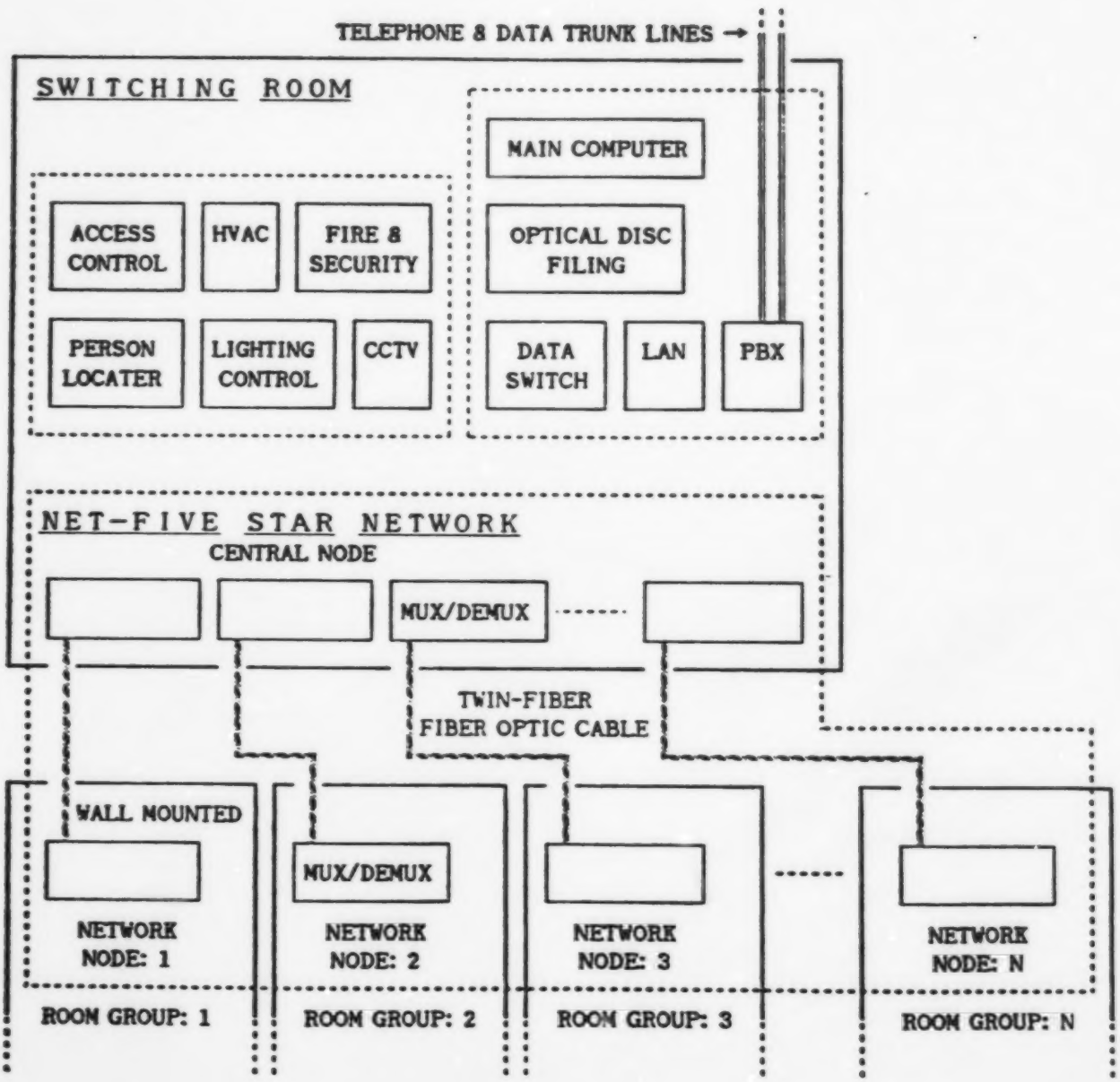

FIG. 1 NET-FIVE FOURTH UTILITY NETWORK

TABLE 2 COMPARISON OF FIBER OPTIC RING AND STAR NETWORKS

The merits of ring and star networks are compared. Support of the fourth utility in an intelligent building is assumed. The ring network is not suited for such applications.

FIBER OPTIC NETWORKS		
	STAR	**RING**
FIBER TYPE	GI MULTIMODE	USUALLY SINGLE MODE
TOTAL FIBER CABLE LENGTH	LONG	POTENTIALLY SHORTER HOWEVER, CLOSE TO STAR IN PRACTICE
VULNERABILITY TO CABLE BREAKS	LOW (NODE ONLY)	HIGH
CONNECTOR COST	LOW	HIGH
BIT RATE	LOW < 130 Mb/s PER NODE/ARM	HIGH > 130 Mb/s OPERATING
COMPONENT COSTS	LOW	HIGH
CONNECTION COSTS OF HVAC & OTHER SYSTEMS	LOW	HIGH
CONNECTION COSTS OF TELEPHONE LINES	LOW	HIGH
MULTIPLE PBX INSTALLATION	EASY INEXPENSIVE	DIFFICULT EXPENSIVE
CONNECTIONS FOR COMMERCIAL LANs	EASY INEXPENSIVE	DIFFICULT EXPENSIVE
MULTIPLE LAN INSTALLATION	EASY INEXPENSIVE	DIFFICULT EXPENSIVE
ANALOGUE VIDEO & AUDIO CONNECTIONS	EASY INEXPENSIVE	DIFFICULT EXPENSIVE
LOW-COST PLASTIC FIBER CABLE USE	YES	NO

configuration has major advantages in terms of cost and flexibility when the fourth utility of an intelligent building is to be supported.

Once installed, the star network allows ready reconfiguration of systems that are supported by the network because most of the rerouting and connect/disconnect operations can be done at the central node which is located in the Switching Room.

The convenience of the star configuration is apparent when actual installation practices of ring and bus type LANs such as Ethernet and IBM Token Passing are surveyed. The star configuration is often used and in fact, the new IEEE 802.3 10BT standard for the twisted pair Ethernet is a star network.

Universal transparency is achieved by the Net-Five network through a high speed Mux/Demux (Multiplexer/Demultiplexer) unit with slots that accept interface cards. Although the unit uses a fiber optic transmission line to carry the multiplexed signals between the units, standard copper wire connections are offered to a user by these cards. As a result, only routine knowledge of electronics is needed for installation and maintenance.

Specifications of the Mux/Demux mainframe are listed in Table 3. Standard high speed multiplexer ICs (Integrated Circuits) are used to provide an aggregate of 100 Mb/s channel capacity. This capacity is divided among the interface card slots according to the types of interface cards that are used. This variable "bandwidth" allocation combined with a wide range of interface card options, provides the Net-Five Mux/Demux with a powerful means of support for the fourth utility needs of an intelligent building.

The fiber optic module with a 100 Mb/s digital multiplexer for the Net-Five Mux/Demux has already been assembled and tested together with some interface cards. Printed circuit boards for new interface cards are being designed at present. Table 4 lists the interface cards that have been developed to date.

As indicated in Fig. 1, the central node of the Net-Five star network is located in the switching room where the building management and telecommunication systems are located. The intelligence of a building is determined primarily by the expertise contained in these systems. If needed, a separate switching room/node can be established for some systems such as the fire detection & control system.

A 19" rack containing a collection of Mux/Demux units constitutes the central node. Copper wire connections are made from this node to the appropriate system. The network nodes are Mux/Demux units located strategically throughout the building. Depending on the demand for telecommunication capacity, between 5 to 10 offices can be supported by a single Mux/Demux unit. They can be mounted chest-high in a wall for convenience.

TABLE 3 NET-FIVE FIBER OPTIC MULTIPLEXER/DEMULTIPLEXER

Features of the Net-Five Multiplexer/Demultiplexer are listed below. The use of plug-in interface cards allows the unit to support a wide range of systems and services. Although fiber optic transmission lines are used as the transmission medium, the input and output connections are made through copper wires.

NET-FIVE FIBER OPTIC MULTIPLEXER/DEMULTIPLEXER
• **NUMBER OF SLOTS IN THE MAIN FRAME** X 1 Fiber Optic Module Card Slot X 13 Interface Card Slots • **DIGITAL CAPACITY PER INTERFACE CARD SLOT (FULL DUPLEX)** Bit rates are logically allocable to each slot (i.e. variable bandwidth) and the aggregate bit rate is than 100 Mb/s.
• **FIBER OPTIC MODULE CARDS** The digital signals are multiplexed into a 100 Mb/s bit stream. Housekeeping signals bring the bit rate up to 125 Mb/s. Fibers in the twin-fiber cable are GI multi-mode 50/125 or 62.5/125. **1. MEDIUM DISTANCE 125 Mb/s DIGITAL CARD (FULL DUPLEX)** [Designed 1991/09/01] 3 km Transmission Distance (Maximum) 1300 nm LED 50/125 Twin-Fiber Cable **2. SHORT DISTANCE 125 Mb/s DIGITAL CARD (FULL DUPLEX)** [Completed 1991/05/01] 2 km Transmission Distance (Maximum) 820 nm LED 50/125 Twin-Fiber Cable

TABLE 4 NET-FIVE INTERFACE CARDS

Interface cards that are completed or nearing completion are listed. Other cards to meet the diverse needs of the fourth utility of an intelligent building will be developed in the near future.

NET-FIVE INTERFACE CARDS COMPLETED OR UNDER DEVELOPMENT

8 CHANNEL RS-232C ASYNCHRONOUS MULTIPLEXER CARD
RJ-11 Plastic Jacks [Completed 1991/6/01]

8 CHANNEL RS-422 ASYNCHRONOUS MULTIPLEXER CARD
RJ-11 Plastic Jacks [Completed 1991/6/01]

ETHERNET BRIDGER CARD
10 Mb/s Throughput [Completed 1991/07/01]

4 CHANNEL T1 MULTIPLEXER CARD
[Completed 1991/09/01]

4 CHANNEL ANALOGUE TELEPHONE LINE CARD
[Completed 1991/08/01]

4 CHANNEL ANALOGUE TELEPHONE PBX LINE CARD
[Completed 1991/08/01]

4 CHANNEL RS-485 CARD
RJ-11 Plastic Jacks [Completed 1991/08/01]

ARCNET REPEATER CARD
2.5 Mb/s Throughput [Designed 1991/02/01]

ANALOGUE TV (UNIDIRECTIONAL)
WITH DIGITAL RS-422 (FULL DUPLEX) CARDS
[Designed 1991/06/01]

1 km Transmission Distance (Maximum)
50/125 Twin-Fiber Cable

ANALOGUE TV and One Direction of RS-422

TV TRANSMITTER		TV RECEIVER
680 nm Laser Diode		PIN Photodiode
Input X 1	Baseband Video	Output VHF CH-2
X 1	Baseband Audio	
One Direction of RS-422		RS-422
RS-422 Return		
PIN Photodiode		820 nm LED

Wiring to each office is done by copper wires over a short distance. A cable approved for plenum wiring would be the simplest to use. The type of cable and termination connectors are dictated by the application.

The Net-Five network basically corresponds to the Physical Layer (i.e. Level 1) of the ISO (International Standards Organization) 7-layer OSI (Open Systems Interconnection) Reference Model. In other words, it effectively replaces the core section of the multitude of copper wire networks in a building with a single fiber optic star network while retaining standard copper wire connections to the various systems that it supports.

Most, if not all, fourth utility needs of an intelligent building can be met by the Net-Five network in a transparent way through suitable interface cards. Some examples are described briefly in the following section.

3.1 NET-FIVE FOURTH UTILITY NETWORK APPLICATIONS

Figure 2 shows an application where two PBX (Private Branch Exchange) telephone systems are supported. The telephones can be analogue or ping-pong mode digital telephone sets. Centrex P-Phones can also be supported. In the future, when ISDN (Integrated Services Digital Network) telephone sets are introduced, the cost of the interface cards will be reduced significantly because simple line driver and line receiver ICs can be used.

The number of PBXs is not limited to 2 but can be increased. Such a flexibility addresses the issue of shared tenant services which has not been a success because of the perception that confidential information may be intercepted by a third party.

By offering more than one PBX, users wishing a dedicated service can be satisfied while those who share a PBX can be offered telephone service at a lower cost.

Figure 3 shows an example of PC networking using low cost RS-232C lines. Normally, such lines should not be extended to long distances such as 100 m, particularly in electrically noisy environments. However, fiber optic cables can extend the reach to more than 2 kilometers.

Data switches for RS-232C lines offer the lowest cost interconnection of PCs. Most data switches have spooling functions to allow sharing of a laser printer without the worry of waiting. Shared trunk line connections on a first-come-first-served basis can also be provided for connections to a computer mainframe.

As in the case of the PBX, more than one data switch can be installed to cater to the demand for low cost PC networking or to satisfy the desire for security.

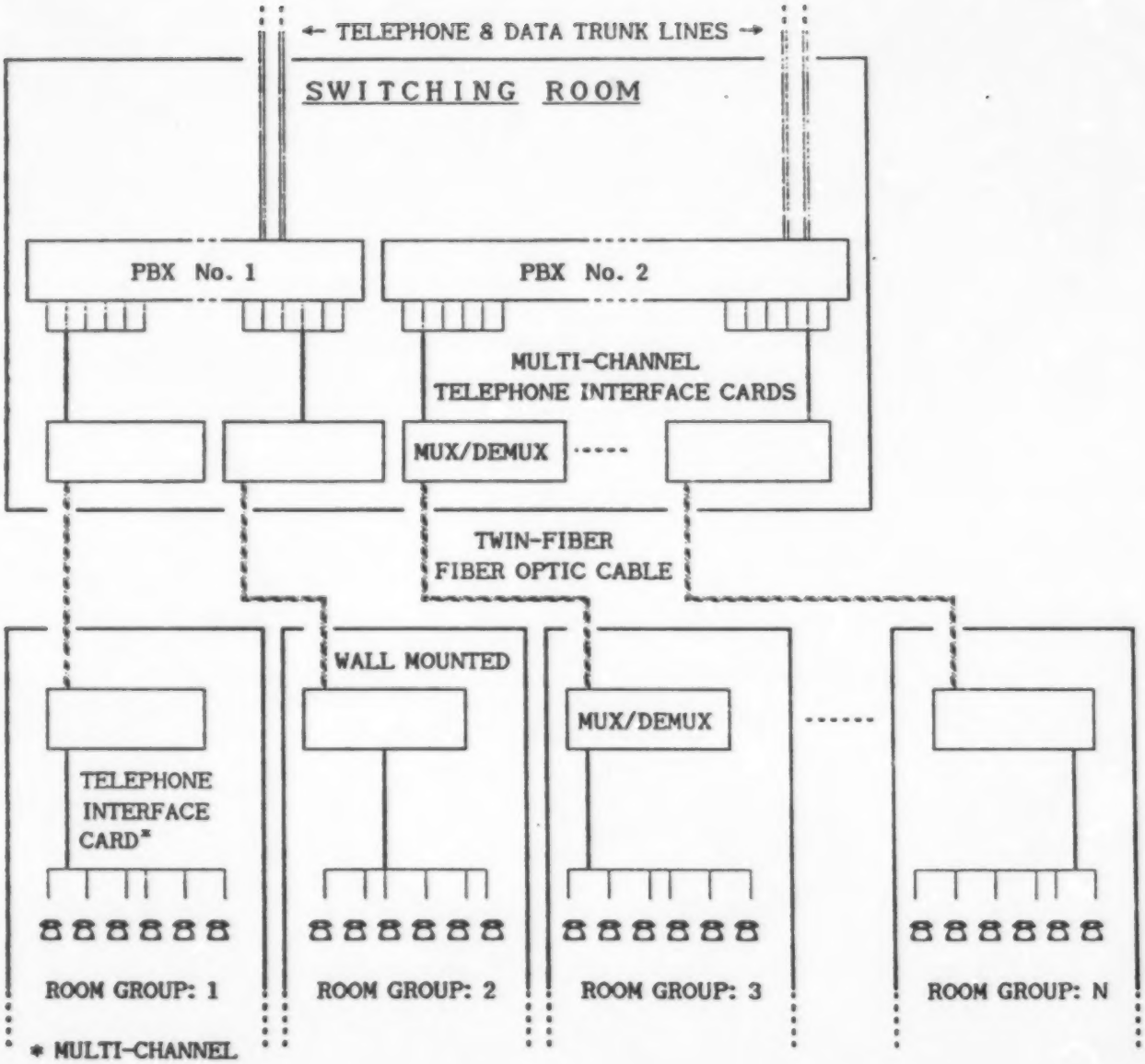

FIG. 2 TELEPHONE PBX APPLICATION

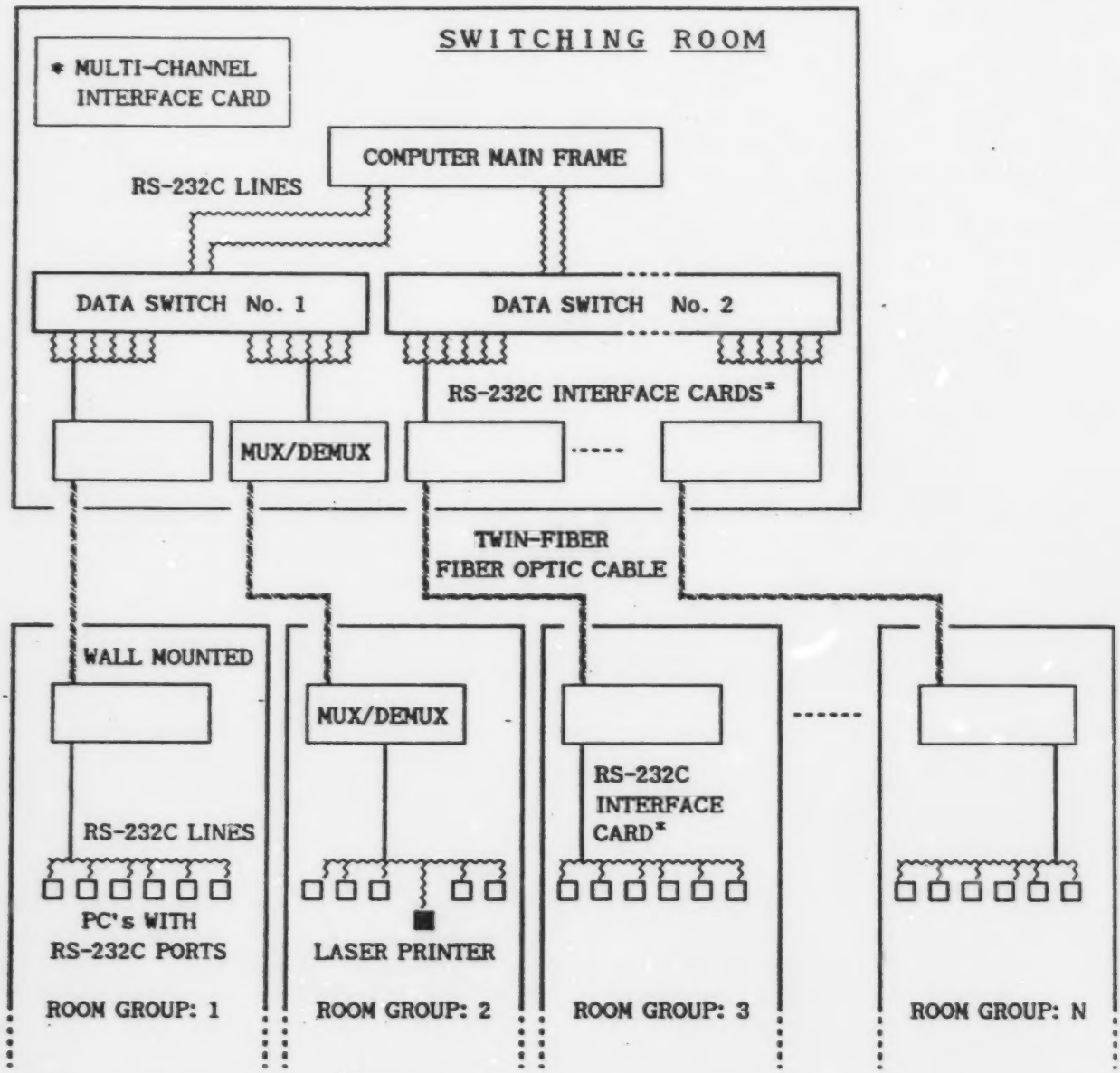

FIG. 3 PC RS-232C NETWORK APPLICATION

In some applications, an RS-232C PC network will present a bottleneck when a common data storage file is to be shared by many users. The limited transmission speed (e.g. 19.2 kb/s or 38.4 kb/s) is the main cause. In such cases, a TDM (Time Division Multiplex) LAN such as Ethernet should be used. Figure 4 shows an example.

Since the copper wire lengths are short in the Net-Five network, an Ethernet using low cost copper wire twisted pairs can be used. Again, more than one Ethernet or a mix of LANs such as Ethernets and Arcnets can be installed to meet the special needs of users and idiosyncrasies of some computer service managers.

Figure 5 shows an application to an HVAC system. Since many low bit rate signals and narrowband analogue signals can be transmitted through a single interface card, extra sensors (e.g. thermometers, flow meters & hygrometers) can be installed to provide personalized climate control as well as efficient energy management.

A good access control system will not only make the work place safe but also improve the after-hours security of a building. When a person locator/pager system [1] is added to the access control system, the security of a building is improved significantly. Factory sites will probably benefit most from such a system.

Figure 6 shows an application to an access control system. If the input/output signal formats to the remote controller are known, they can be located in the switching room to serve a larger number of card readers and door locks thereby reducing the cost of a system.

Fire codes normally specify an independent wiring for fire & security systems but the availability of many telecommunication channels at low cost presents an opportunity to design a reliable fire detection & control system. Figure 7 shows such an example.

Wiring from smoke detectors and temperature sensors can be connected to two different Mux/Demux units to provide redundant connections. As a second choice, they can be connected alternately to two different Mux/Demux units in a interleaved fashion. This way, every other room will be protected if a set of Mux/Demux units fail.

It should be emphasized that the breakdown of a set of Mux/Demux units affects only those rooms supported by this set and the remainder of the Net-Five network is not affected. The breakdown is detected immediately by the status monitoring circuitry built into each Mux/Demux pair and a warning given to the maintenance staff.

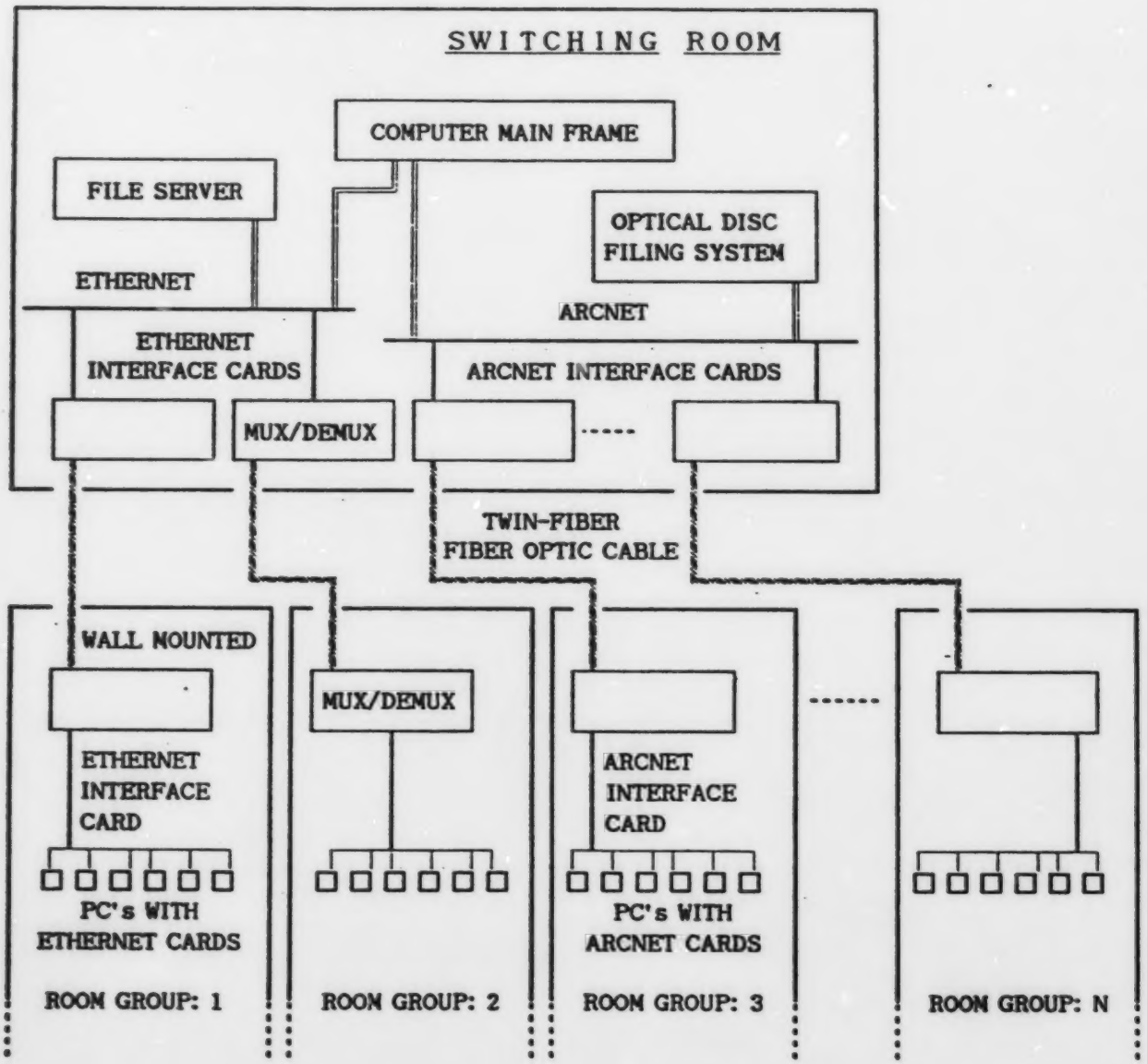

FIG. 4 LAN APPLICATION

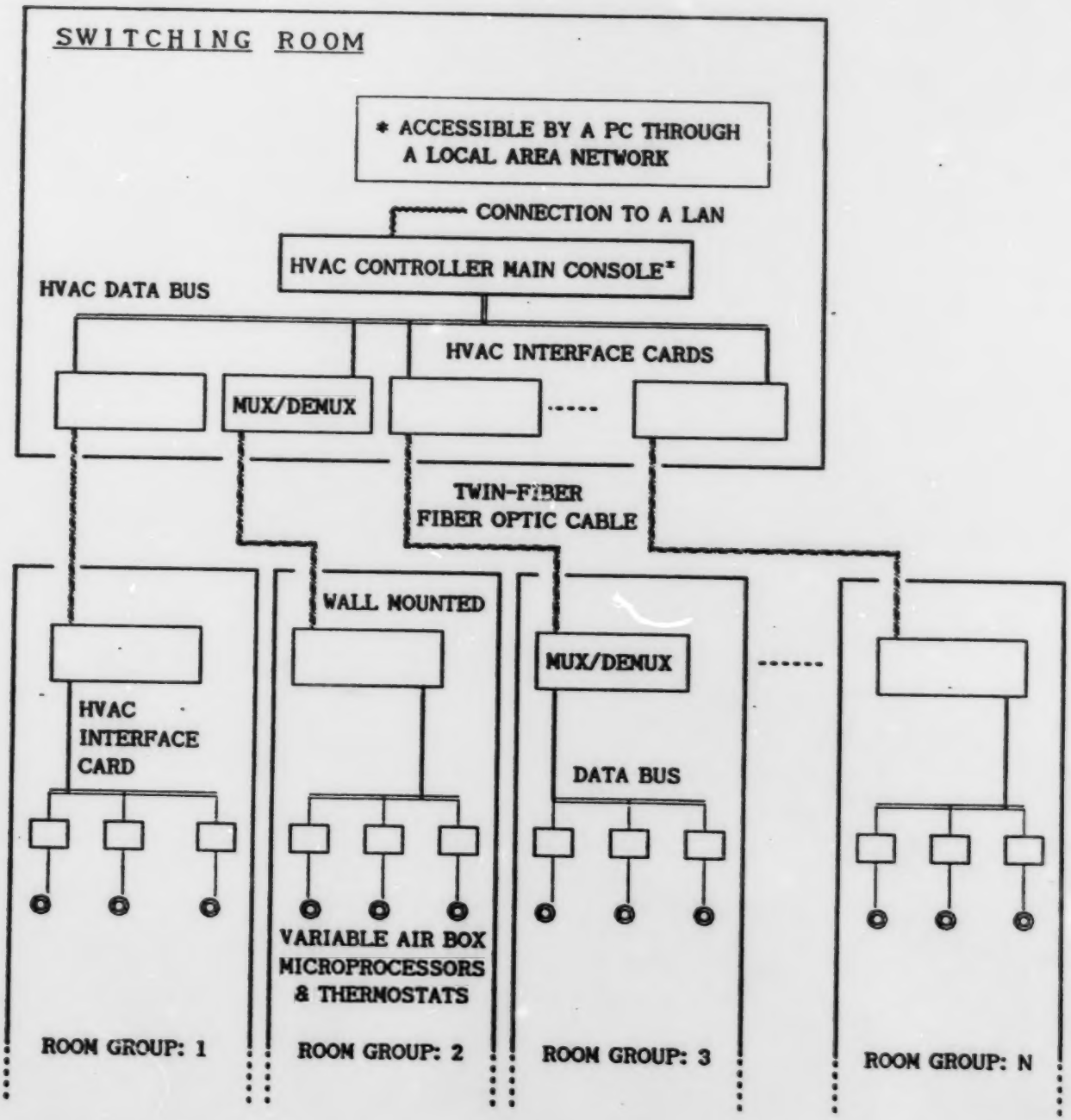

FIG. 5 HVAC SYSTEN APPLICATION

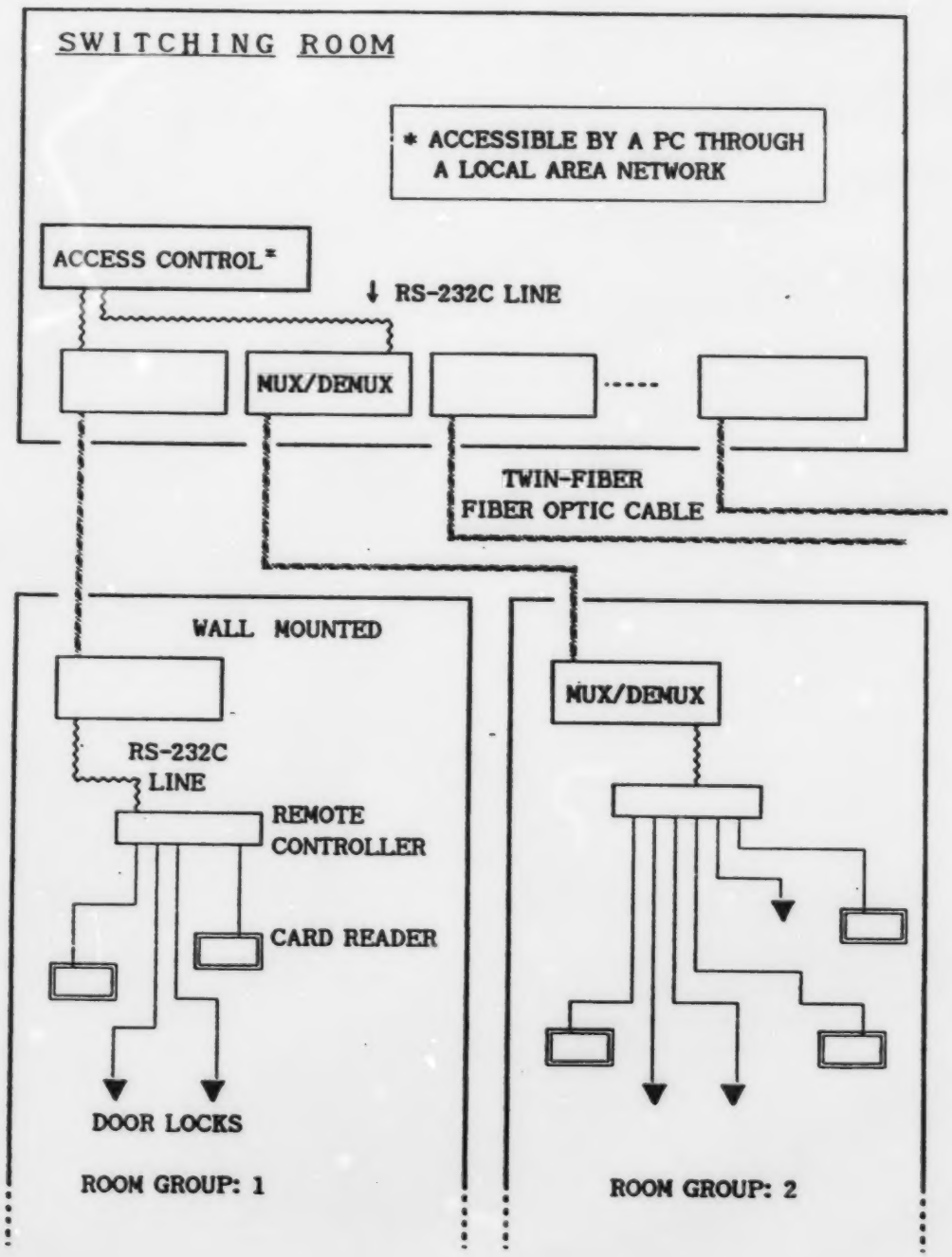

FIG. 6 ACCESS CONTROL APPLICATION

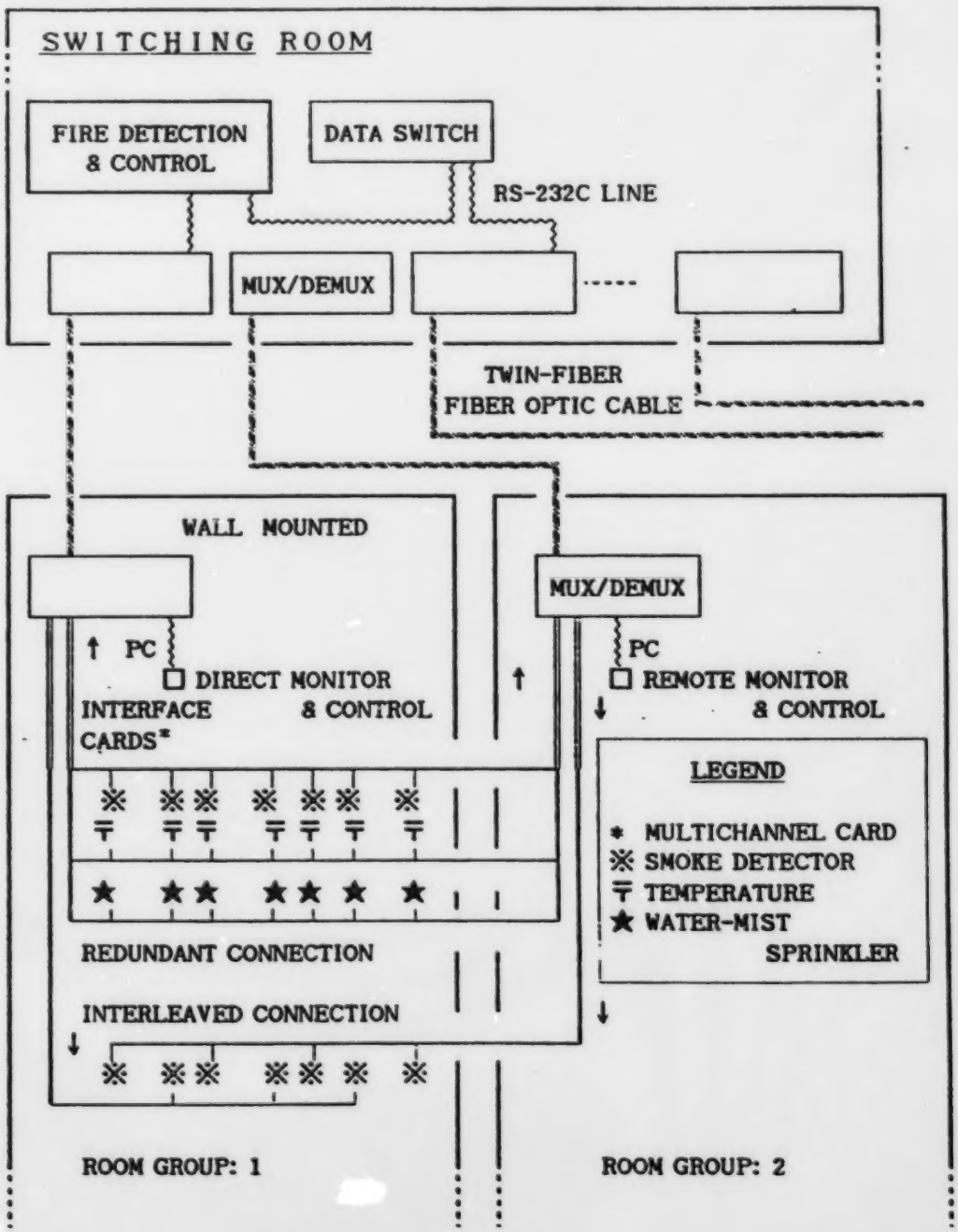

FIG. 7 FIRE DETECTION & CONTROL APPLICATION

The availability of a return channel allows positive control of a sprinkler system. A water-mist sprinkler head can be installed in parallel with standard sprinkler heads. When the smoke density and temperature information indicates to the fire detection & control console that a fire has started in a room, an electronic command can activate the water-mist sprinkler.

Fuzzy logic is used by the console to determine the presence of a fire. Activation of the water-mist sprinkler can take place much earlier than the standard fuse-type sprinkler head because smoke density and temperature information are processed together to make a human-like decision.

It should be noted that water-mist will cause less damage to equipment and only one sprinkler head is needed in a typical room. Also, the water-mist sprinkler is installed in parallel to the standard fuse-type sprinkler head and the redundancy improves the safety of a building. At CIBINT, development work has already started on this system with an eye on applications to factories and processing plants.

By using the fiber optic card that can carry analogue TV signals, security monitoring by CCTV becomes possible. Since the card is designed to carry audio signals as well, surveillance by sound is also possible. An application is shown in Fig. 8.

In the present design, a separate twin-fiber cable is used instead of a WDM (Wavelength Division Multiplexing) scheme because the cost of extra fibers in a cable does not increase the system cost significantly. One fiber is used for TV transmission while both are used by the RS-422 digital data channel.

Note that low cost TV receivers can be used because the signals are delivered on channel 2. If required, the RS-422 digital data channel can be used to tilt, pan and zoom the TV camera.

Figure 9 shows a 128 X 20 Mb/s = 2.6 Gb/s LAN. A 128 X 128 semiconductor spatial (i.e. circuit) matrix switch is used to interconnect 128 high speed terminals on a non-blocking basis. Here, non-blocking means that, if the called party is already connected to another terminal, connection on a time division multiplex basis is guaranteed.

There are a number of commercial spatial matrix switches that can be used as the LAN matrix switch. The electronic circuitry associated with it is simplified significantly by a unique design.

The 2.6 Gb/s LAN can readily support Sun Microsystem high speed work stations. If 50 Mb/s interconnections are required, they can also be supported. Of course, the channel capacity of the Net-Five Mux/Demux will be limited to an aggregate bit rate of 50 Mb/s if a 50 Mb/s channel is supported.

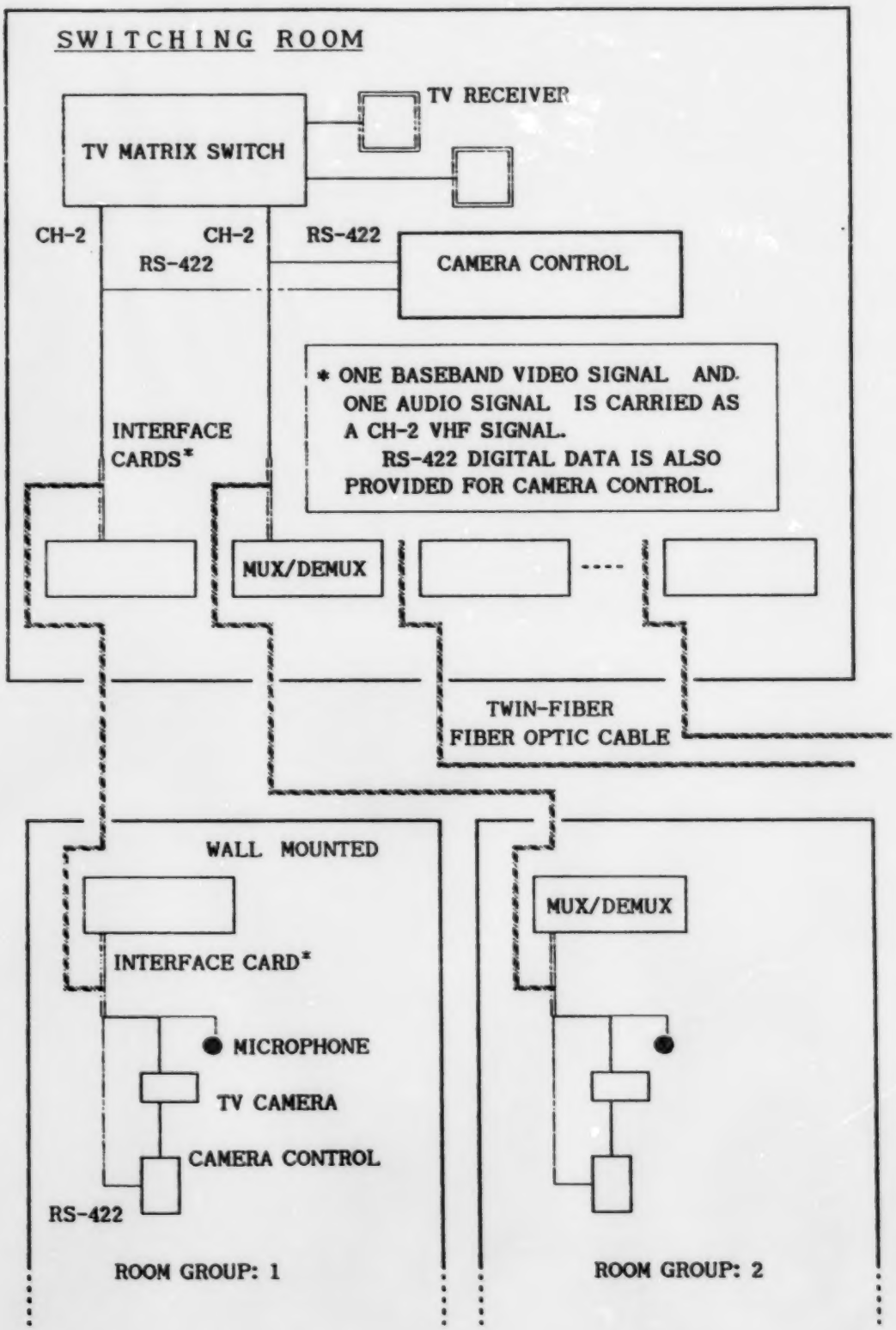

FIG. 8 AUDIO & VISUAL CCTV SURVEILANCE APPLICATION

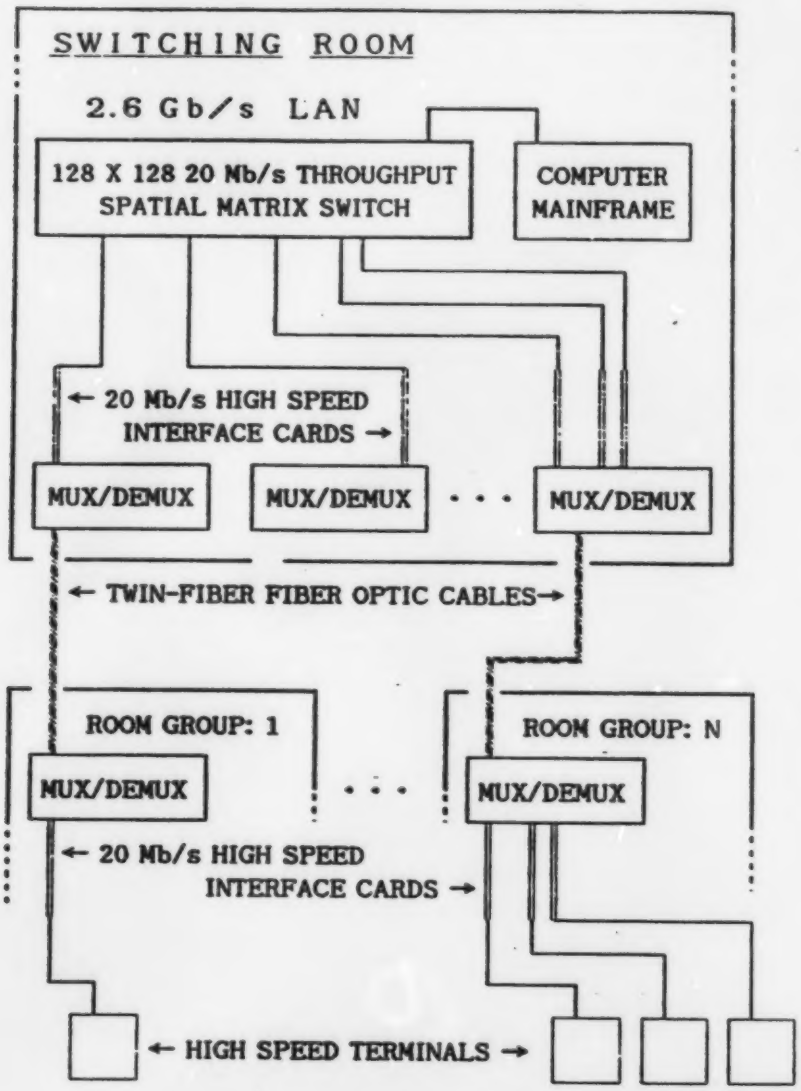

FIG. 9 2.6 Gb/s 128 X 128 SPATIAL MATRIX SWITCH LAN

Systems supported by the Net-Five network are not limited to those mentioned above but can extend into lighting control, person locator/pager and many other systems that increase the IQ (Intelligence Quotient) of a building.

Since very simple electronic circuitry is used in the interface cards, for most applications they can be prototyped in less than 6 weeks, once the signal format is known. Information on the signal transmission protocol is not required in most cases.

4.0 IMPACT OF THE TECHNOLOGY ON THE CONSTRUCTION PROCESS

The concept of a single fiber optic network that supports the telecommunication needs (i.e. fourth utility) of buildings, factories and campuses is not new but the manner in which the Net-Five Fourth Utility Network brings the concept into practice is novel. Because of this novelty, some of the traditional approaches in the construction industry will need to be altered before benefits of this new technology can be enjoyed widely.

One of the basic issues is symbolized by Fig. 1. Obviously, the network and various systems cannot be selected and installed independently as is the practice today, if a sound return on capital expenditures is desired. Careful planning and coordination will be needed right from the conceptual design stage.

Compared to conventional wiring schemes, the sizes of conduits, raceways and wiring closets can be smaller. If a home-run fibering scheme is adopted, many conventional wiring closets can be eliminated. The Mux/Demux units must also be located strategically and installed chest-high for convenience in wiring.

Also, close attention must be paid to the central switching room/node. Adequate floor space and electrical power as well as good ventilation must be provided. It would be best to consider the switching room/node as the nerve centre of the building and treat it accordingly.

In addition to the forth utility network, a wide range of systems including HVAC, LANs, PBXs and CCTV must be dealt with. This points to the need for a Fourth Utility General Contractor who can expertly oversee the entire operation from inception to the final tests.

In an era where it is difficult to get the Director of Telecommunications and the Director of Computing Services to agree on technical matters, it may appear even more difficult to have various building management system suppliers to agree on the merits of a single fourth utility network.

Fortunately, a standard telecommunication protocol for building management systems is being promoted strongly by the Department of Public Works, Canada, with good cooperation from

the industry. It is hoped that the cooperation will be extended to a point where placing a proprietary signal on a fourth utility network in a transparent way becomes acceptable.

It should be emphasized that standards are not an issue for the Net-Five network because of its flexible and transparent design, but interface card costs will be lower if a limited number of standards are established. From this point, the move of the telecommunications industry towards ISDN is most welcome.

The emergence of a Fourth Utility General Contractor will be aided if major beneficiaries of the technologies, those who hold financial interests in the efficiency of a work force, were to demand the installation of fourth utility and other systems that can increase productivity.

Therefore, because of their size, the Department of Public Works, Canada, and Property Management Departments of Provincial Governments can facilitate the establishment of a Fourth Utility General Contractor by specifying conditions that will lead to an increase in productivity, for the offices under their management.

Developers of office buildings can also benefit by offering a high productivity work place because knowledgeable corporations will appreciate the impact of an efficient work force as well as the prestige of having an "intelligent building" address.

Emergence of Fourth Utility General Contractors will also stimulate the formation of a fourth utility industry in Canada. By having a head start, a major share of the world market might be gained through the wide base that the Canadian construction industry has already established.

5.0 DISCUSSIONS

The savings gained in reduction of wiring labour costs and conduit costs partially offset the cost of the Net-Five network. Further gains are made in terms of reduced post- installation debugging costs associated with EMI, RFI and ground loop problems. Expenses connected with office moves and renovations are also expected to be reduced because disconnection/connection operations are simplified. Even major changes in a LAN can be achieved by simple changes of interface cards.

As mentioned at the beginning, staff efficiency can be increased through a healthy, pleasant, secure and safe work place. The argument can be applied to hospitals as well. By providing better OA and telecommunication support as well as a better work climate, staff efficiency can be improved. Support of more and better patient monitoring may also allow the patient load to be increased without a corresponding increase in fatigue and stress factors. These improvements are supported readily by the Net-Five network.

The degree of convenience and efficiency gained by the Net-Five network over conventional copper wire networks might be compared to that between an electric typewriter and PC word processor. Once the convenience and efficiencies are experienced, it will be difficult to revert to the old.

Establishment of Fourth Utility General Contractors is an important issue for the construction industry of Canada because strong competition from Japanese construction companies such as Kajima, Shimizu and Takenaka can be anticipated. Typically, they allocate up to 10 % of their gross income to R & D, in which the intelligent building is a major topic.

Japanese construction companies already operate as general contractors, supplying services from the conceptual design stage to the final opening ceremonies. It is a matter of time before they will also include the complete fourth utility for intelligent buildings, as part of their business. The co-development of the person locator/pager system by OKI Electric and Takenaka reflects this direction.

In the past, Western Union had an opportunity to obtain a major interest in the Canadian operation of Bell's invention. The opinion that the traditional way of telegraphic communication met the business needs of the day prevailed. It is our hope that history will not be repeated again in a similar fashion with the Canadian construction industry.

END NOTE

[1]. *OKI Electric Co. Ltd. and Takenaka Corporation have jointly developed a person locator/pager that can display the location of a person in a building on a central console. Paging is also possible and LED (Light Emitting Diode) indicators show whether a telephone call is waiting, return to the office is requested, visitor is at the reception desk, or a reminder that a meeting must be attended.*

The locator/pager unit is the size of a U.S. cigarette package and signal transmission to the unit is through IR (Infra-Red) optical signals emitted from transmitter units installed in the ceilings. Communications back to the central console is through short wave RF signals from the locator/pager unit. Loop antennas installed in the ceiling pick up the signals which are transmitted back to the central console via copper wire cables.

Coded location query signals are sequentially (i.e. round-robin) transmitted from the IR transmitters. The combined use of IR and short wave RF signals avoid the fading and phase interference problems often associated with wireless LANs that use VHF signals.